Routing in Space Based Internets

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Abstract

Space Based Internets will be used to move earth observation data through satellite constellations to ground based receiving stations. Routing observation traffic in this environment is constrained by individual satellite orbits, individual satellite capabilities, observation schedules, ground station schedules, and rapidly evolving natural events. This paper discusses routing algorithms for Space Based Internets under these constraints.

Keywords: Space Based Internet, Routing, Mobile Networks.

1. Introduction

A Space Based Internet (SBI) is a satellite network system in which each satellite is capable of originating traffic, terminating traffic, and switching traffic traveling between other satellites and the ground. To build a SBI, each Earth observation satellite would carry a communications system with several channels (RF or optical) and a network control processor to switch traffic between the several communications channels and local payload. We expect that most switching will take place at the network layer (Internet Protocol).

The advantages of a SBI in which each observation satellite takes part are several:

- The system is scalable; as each satellite is launched it adds capacity to the SBI.
- Standard SBI modules can be designed, constructed, and deployed to minimize individual satellite cost.
- SBI modules can be enhanced as technology advances - hence the system evolves.
- Special SBI satellites can be designed, constructed, and deployed to provide extended capacity and capabilities.
- Future missions are likely to be "joint" across multiple platforms and programs calling for an integrated communications capability.

- Communications between satellites will be necessary for coordinated data collection, especially for unique events.

As a network, a SBI is different from land-based networks in that links come up and go down based on the orbital mechanics of each satellite and the availability of line-of-sight. However, a SBI is more predictable than an ad hoc network because the orbits, satellite characteristics, and traffic loads are predictable.

In this paper we describe the characteristics of a SBI with respect to routing, and offer initial thoughts on routing algorithms suitable for a SBI.

1.1. Structure of a Space Based Internet

A SBI consists of (1) satellites equipped with a scientific instrumentation payload, a network control processor (router), and one or more communications channels, (2) ground stations to receive collected data and to manage the satellite system, and (3) optional communications only satellites to increase the capacity of the system. For the work reported here we do not distinguish between (1) and (3).

Our model of a SBI satellite node is shown in Figure 1. At the core is a packet switching system that interconnects the input/output channels and the scientific payload. The payload (generally) produces data from Earth or space observations. Once collected, the data is transferred to a ground station over the SBI. Each satellite has at least one, and perhaps several, communications channels. In our model we are not concerned with the details of these channels (e.g. radio or optical, modulation type, access mechanism, or propagation characteristics). We model communications channels as a constant bit rate link with errors and delay.
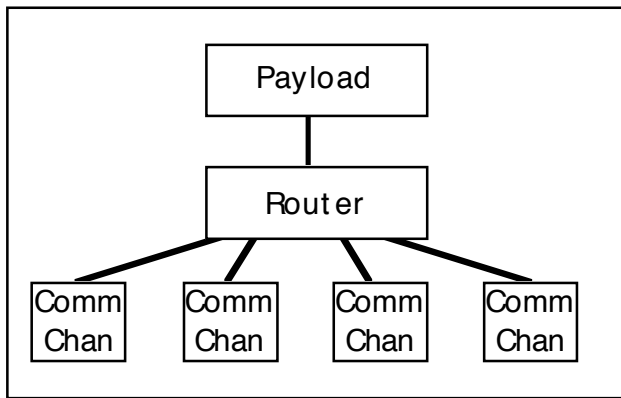
Figure 1. Illustrates our model of an SBI node. A SBI node consists of a payload, a router, and one or more communications channels.

We assume that the Internet Protocol (IP) is used to send, receive, and route data. Each satellite becomes a possible router in the SBI. Our task, described in the next section, is to determine the routes data should take from origin to destination.

2. SBI Routing

A SBI consists of a set of satellites and a set of fixed ground stations. Our task is: Given the satellite and ground station positions (current and near future) and the traffic sources and sinks, determine a set of routes from sources to sinks meeting a set of constraints. A set of routes will be in place for a reasonable length of time, perhaps 10-15 minutes or longer if the orbits allow. We will refer to the length of time a set of routes is in effect as the *epoch*.

Satellites are in Earth orbit at altitudes at or less than geo-synchronous orbits. We assume the orbit of each satellite is well known and given the current satellite position and parameters, the satellite position in the future can be computed.
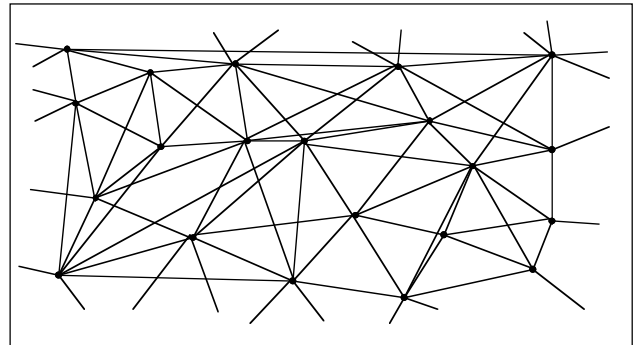
2.1. SBI Topology

The first step in computing a set of routes is to determine possible links between satellites and between a satellite and a ground station. Several criteria are used to determine if a link is possible:

- Is there a clear line of sight path between the satellites or satellite and ground station?
- Can antennas or optical telescopes be positioned to establish the path during the epoch?
- Are the communications channels compatible (i.e. frequency, modulation, capacity, etc.)?

- Will the path exist for a reasonable period of time, the epoch?

These criteria form an initial 'filter' to determine a set of possible links. The result is a graph illustrated by the sample in Figure 2. Graph nodes are satellites or ground stations, edges are possible links, and, in this figure, satellites are position by the latitude-longitude coordinates.

Figure 2. Illustrates the set of possible links taking in to consideration line-of-sight, compatible systems, and antenna constraints. Satellites, represented by nodes, are positioned on a latitude-longitude grid.

2.2. SBI Topology Pruning

The topology resulting from the set of possible links is too rich to implement. Links must be pruned from the possible topology to obtain a topology that can be implemented. Considerations for keeping links are:

- There are a limited number of communications channels available on each satellite; keep the highest capacity channels.
- Some links will be used by more than one source-to-sink path; keep the most useful links.

To determine which possible links are the highest capacity requires an iterative process. High capacity links are important because they (generally) reduce delay and jitter effects. If satellites A and B might be linked, the highest capacity link from A to B might not be in the set of highest capacity links from B. Assume there are N_A possible links with satellite A as an end node and satellite A supports $K_A <= N_A$ channels. While likely carried out in a central operations computer, we can envision satellite A broadcasting to its neighbors the identity of its K_A highest capacity links and receiving from its neighbors their highest capacity links. If there is a match, a link is kept. If a neighbor 'rejects' a link, satellite A tries the next highest capacity link. Likewise during this 'negotiation,'

a higher capacity link from B to A, initially rejected, might become available and A would decide to form a link with B.

To determine the most useful links, we can compute the shortest path from each source to its designated sink. The more paths crossing a link, the more useful that link.

Using these two criteria, the set of possible links is pruned to a set of implemented links. Figure 3 shows a typical pruning.
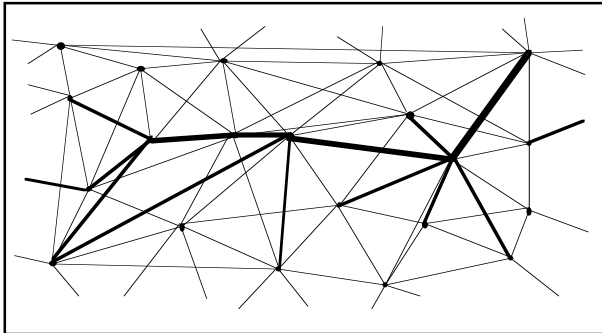
Figure 3. Illustrates a pruned topology. Possible links are thin lines and selected links are thicker lines.

2.3. SBI Routing

Once a topology has been determined, routes from sources to sinks can be determined. In conventional land-based networks, destination addresses are separated into a 'network' address and a 'host' address. Each router maps the 'network' prefix to an output channel. However, in the SBI, there are relatively few nodes and routes are likely to change during the duration of a transmission. Hence, routers are likely to map a full 'network' and 'host' destination address to an output channel. For even several hundred destinations, this is not onerous.

A source node, using conventional network control programs, will not have trouble sending data on a different output channel. However, the sink establishes a single destination address/port for the receiving application and must be prepared to accept packets for that application/port on any incoming channel. This is slightly different from the convention of assigning addresses to interfaces.

In a centrally managed operation, topology and routes are determined at an operations center and transmitted to each satellite. The operations center can base the topology and routes on satellite position, orbital mechanics, and satellite communications capabilities.

One aspect of an SBI that differs from land-based networks is that updating the routing tables must be carefully sequenced. If a link is scheduled to go down, the source routing table must first be updated to stop transmitting on the link, and then each router along the path between source and sink must be updated, but not until all the traffic has transited the link that is going down. In an SBI this transition from one set of routes to another may take several hundred milliseconds.

3. Conclusion

We have characterized topology determination and routing in a Space Based Internet. Determining a topology depends on satellite location, line-of-sight, and communications channel characteristics. Further pruning of the topology is based upon measures such as capacity and usefulness of the link. Once a topology is determined, routes from source to sink can be computed. Changing these routes requires careful sequencing of changes to the routing tables on each satellite.

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